NFRad—A Review of the New NIST Noise Measurement System.

C.A. Grosvenor, J. Randa, and R.L. Billinger

RF Technology Division
National Institute of Standards and Technology
Boulder, CO

55th ARFTG Conf., Boston, 6/00

Important Requirements and Features

- Designed to permit practical noise parameter measurements.
- Need speed, stability, repeatability.
- Byproduct: much less temperamental than old systems.
- Several “extra” features not needed for noise temperature measurements.

- Speed:
  - Electronic switching.
  - Lookup tables for ''’s and 0’s; measured on vector network analyzer. Old radiometers used built-in six-ports.
  - Requires stability and repeatability of ''’s and 0’s over months or years.
  - Ten times as fast as old coaxial radiometers. Can calibrate about 10 to 15 frequencies in one day (DUT + check standard, 3 ports each).

- Stability:
  - Relevant time periods - several minutes to several hours.
  - Radiometer gain and noise figure must be stable over a few hours so that can calibrate it with cryogenic standard & then use cryo standard for amplifier input. (Not needed for noise-*temperature* measurements.)
  - Achieved by:
    - minimizing stress in receiver's mechanical design
    - water plates for lossy elements
    - water plates for temperature-sensitive components (mixers and rf amplifiers).

- Repeatability & long-term stability:
  - Switches: average over many (50) readings.
  - Connections: table top designed for good, repeatable connections.
  - Other: long-term stability and repeatability from mechanical design of receiver and water plates for sensitive components.
- Stability and repeatability results will be shown in testing section.

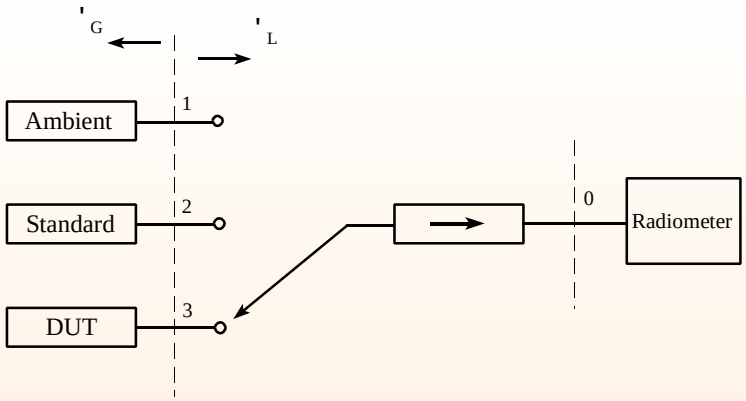
- General system properties (8–12 GHz unit)
  - < Noise temperature . 450 K (at 8 GHz)
  - < Gain . 100 dB
  - < Sensitivity: Std. dev. of mean . 3 K

Old System	New System
Only one frequency can be measured per day.	10 to 12 frequencies can be measured per day.
Calibration of six-port needed.	No six-port calibration is needed.
Can only measure 2 devices.	Can measure up to 4 devices at the same time.
Electrical Stability-marginal.	Designed for good electrical and mechanical stability.

Temperature of unknown calculated using:

$$T_x = T_a + (T_s - T_a)\frac{M_s h_s}{M_x h_x}\left[\frac{\frac{P_x}{P_a} - 1}{\frac{P_s}{P_a} - 1}\right]$$

- x, a, s refer to the unkown, ambient and cryogenic standard, respectively.
- M_x and M_s are the mismatches at the DUT port and cryogenic port, respectively.
- 0_x and 0_s are the path efficiencies between the DUT port and radiometer and the cryogenic port and radiometer, respectively.
- T refers to temperatures, P refers to measured powers.

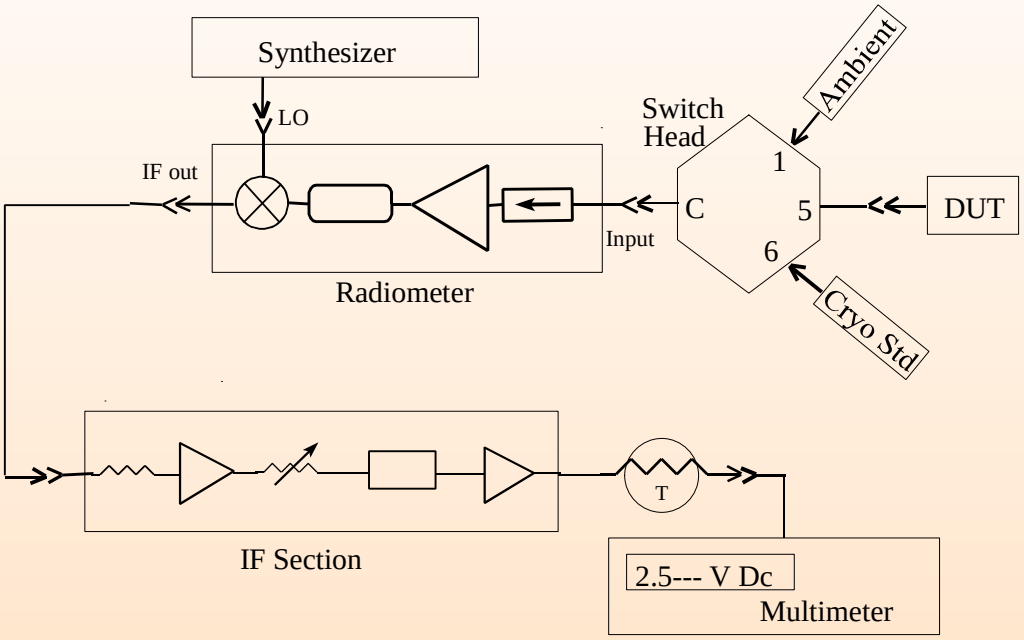


- M_x (referred to above) is the mismatch at plane 3, M_s is the mismatch at plane 2.

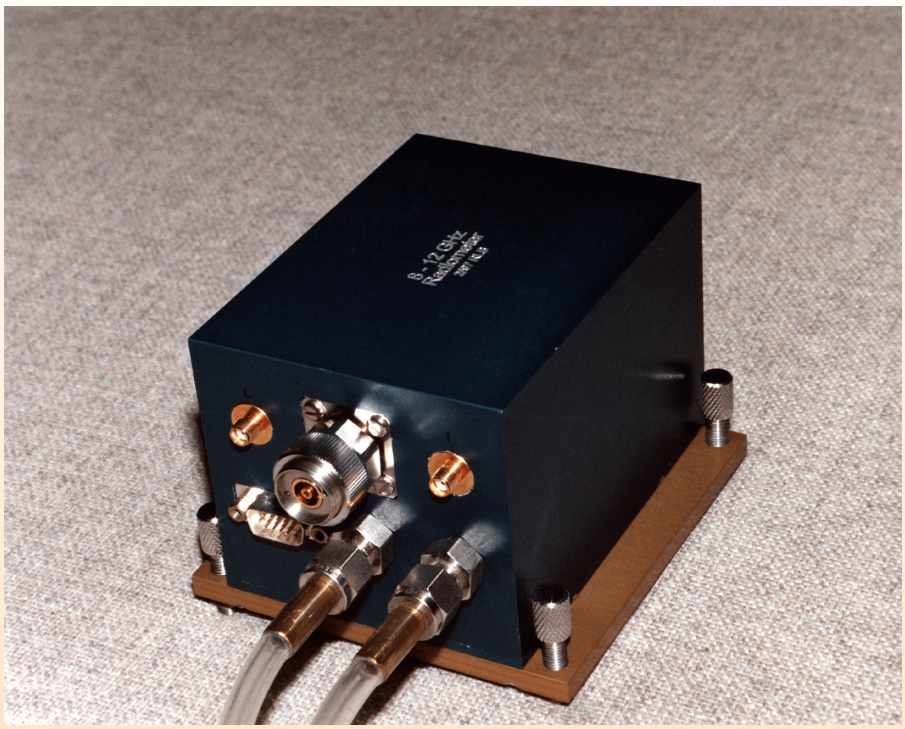
$$M_x = \frac{(1-|\Gamma_{DUT}|^2)(1-|\Gamma_L|^2)}{|1-\Gamma_{DUT}\Gamma_L|^2}$$

- 0_x is the path efficiency from plane 3 to plane 0, 0_s is the path efficiency from plane 2 to plane 0.

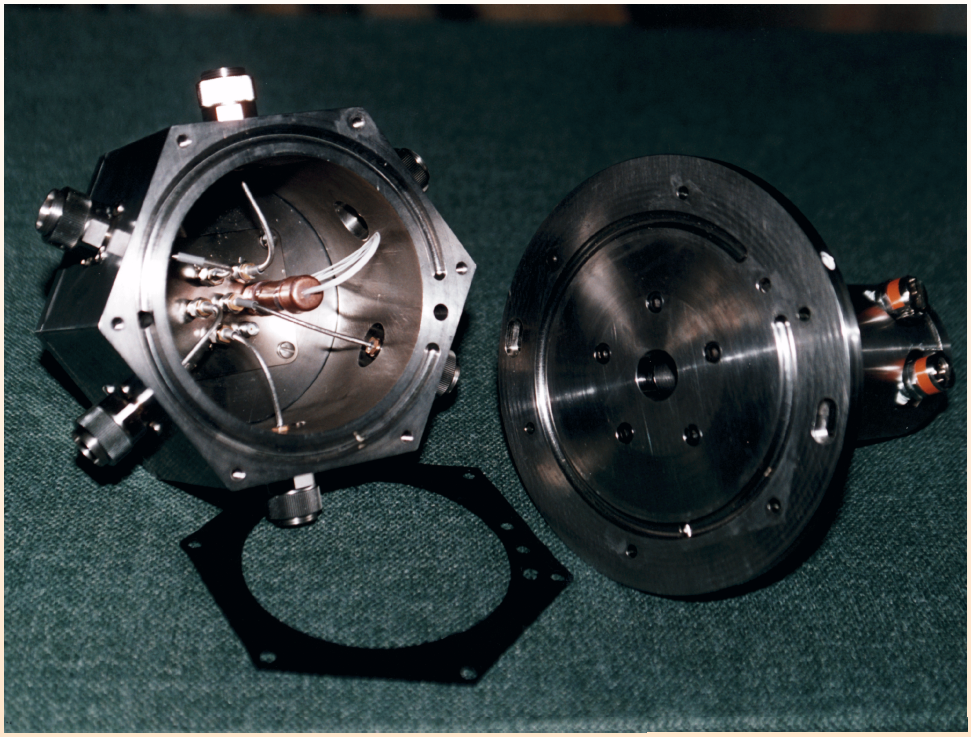
System Block Diagram



8 to 12 GHz Radiometer



Interior View of Switch Head Assembly



Testing

- **Ambient Testing (should measure ~296 K)**
  - 3 Thermistors used to calculate temperature
    - In switch head
    - In radiometer housing
    - Just before water enters cryogenic standard

$$T_{Celsius} = \frac{T_2 - T_1}{R_1 - R_2}(R_1 - Meas) + T_1$$

T_1, T_2, R_1, R_2 are known calibration constants

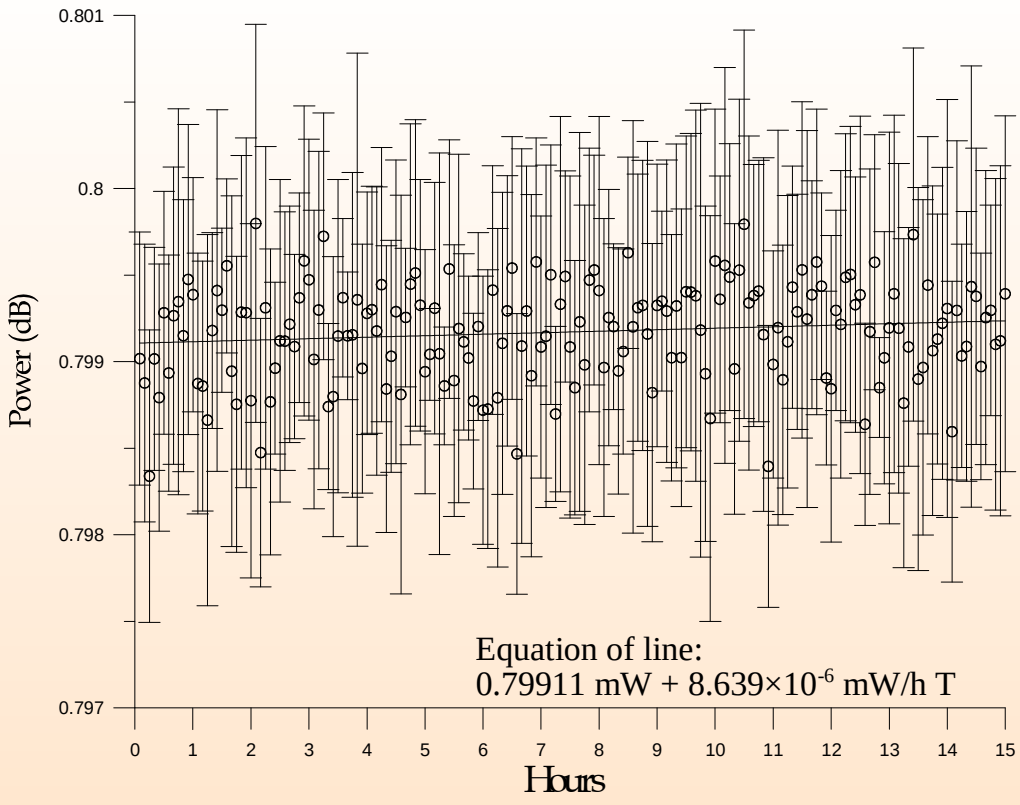
Meas is the measured resistance of the thermistor

- **Cryogenic Testing**
  - Compare calculated boil-off temperatures with known values.
  - Correct for losses in coaxial line.
  - Value should compare to previously calculated values.

P Stability

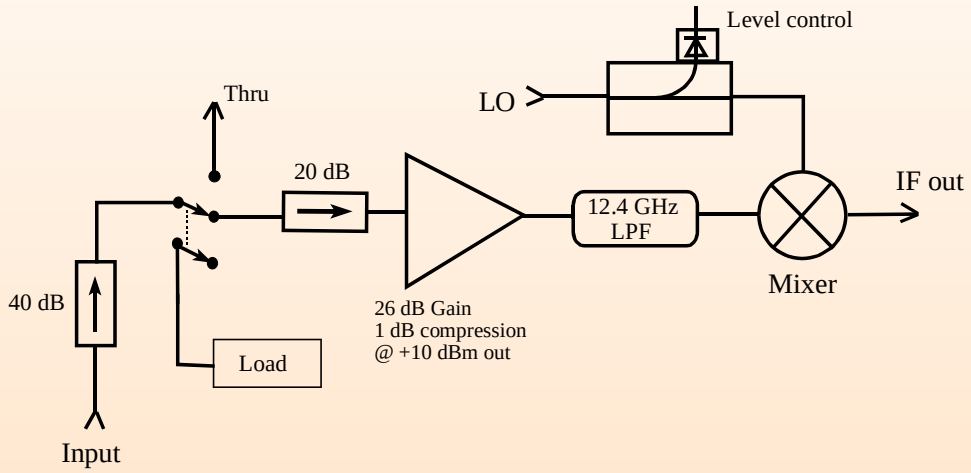
- < To ensure the system does not drift appreciably
  - – Type IV power meter off (baseline),
  - – ambient standard
  - – cryogenic standard
  - – check standard
  - – DUT

- < Procedure
  - – Track power and temperature for a certain period of time, in our case we measured for 15 hours.
  - – Our 8 to 12 GHz radiometer drifted no more than 0.001 percent per hour.

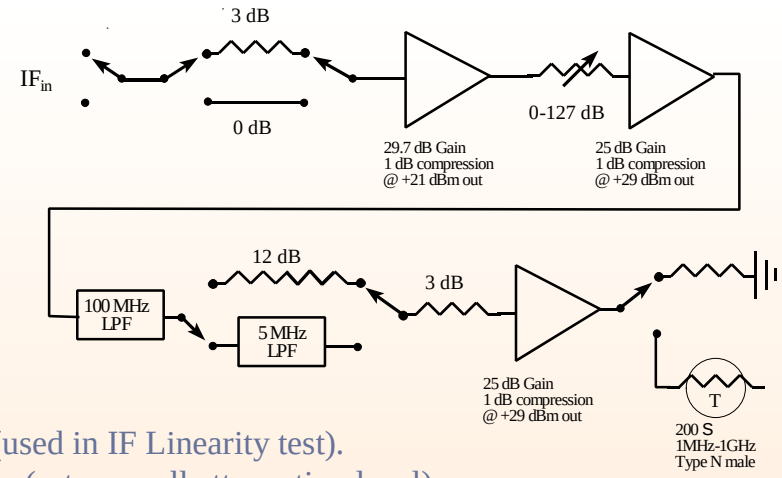


P Isolation

- < Measure isolators in front of system to ensure that amplifier response is not dependent on source impedance.
- < In the 8 to 12 GHz radiometer, total isolation measured > 60 dB across band.

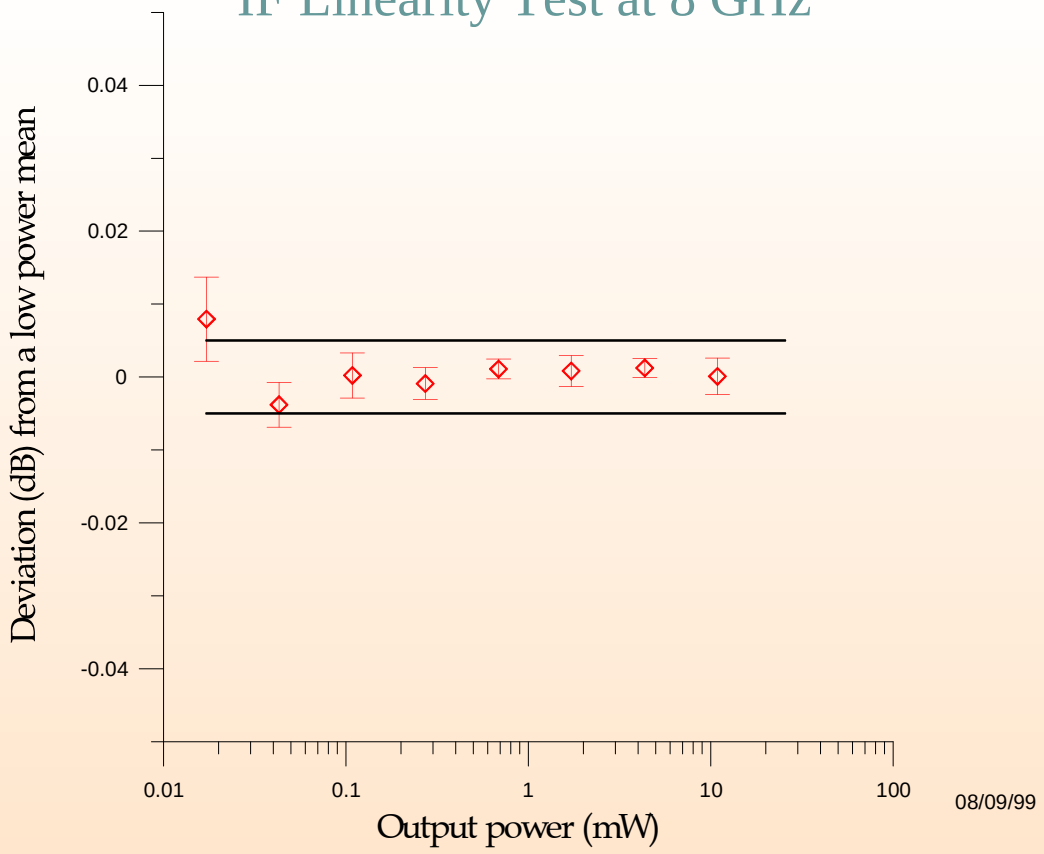


P Linearity



- < IF Linearity
  - – Components
    - – 3 dB attenuator (used in IF Linearity test).
    - – 127 dB attenuator (sets overall attenuation level).
    - – 5 MHz or 100 MHz low-pass filter (sets IF bandwidth).
    - – Amplifiers increase signal from ~ 4×10^{-10} W to ~ 2 mW.
  - – Testing
    - – Determines linear operating range of IF Section.
    - – Procedure
      - – 127 dB attenuator stepped from -40 dB to 0 dB.
      - – 3 dB attenuator stepped into and out of circuit at each setting.
      - – Ratio of power with 3 dB out to power with 3 dB in, is plotted vs. Input power.
    - – System considered linear if ratio is within ±0.1 percent.

IF Linearity Test at 8 GHz



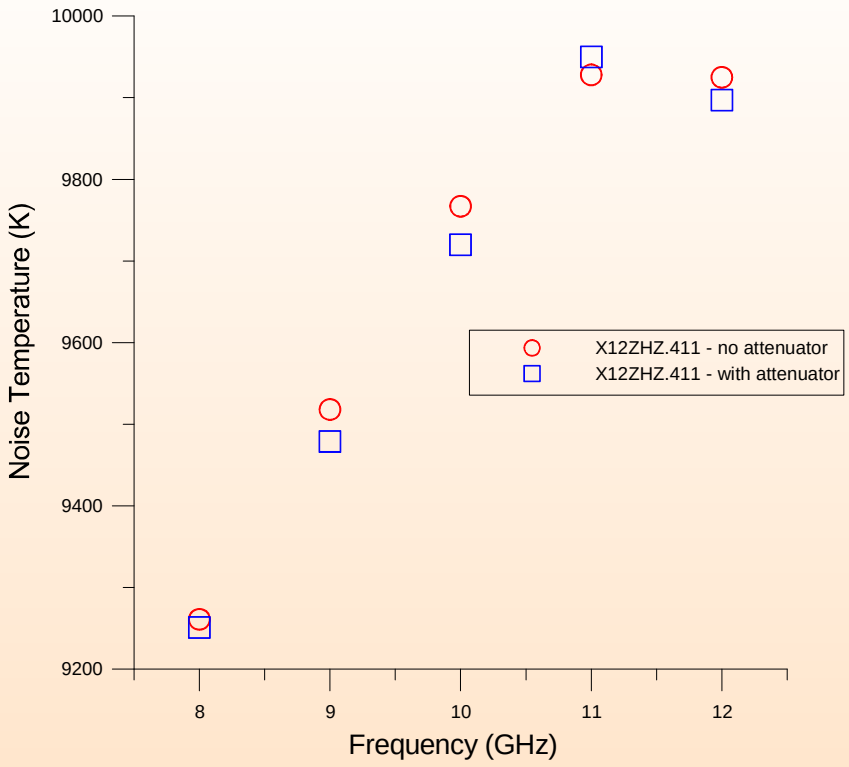
P Mixer Linearity Test

- < Ensures small change in L.O. power does not result in large change in output power.
- < Must agree to within 15 K for 3 dB change in synthesizer output power.

P RF Linearity Test

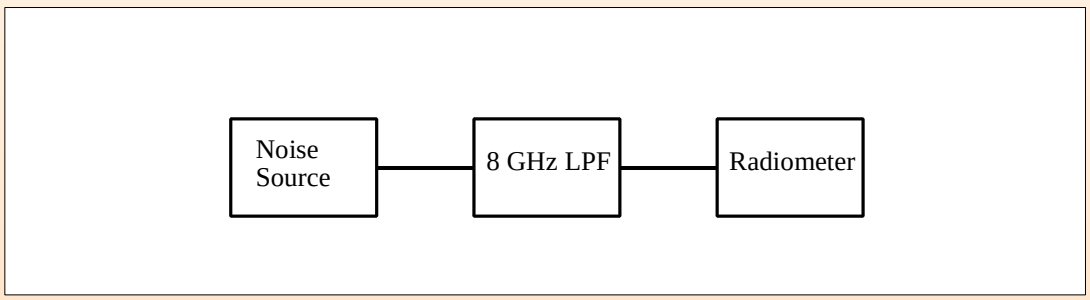
- < Tests linearity of entire system.
- < Insert 3 dB attenuator in path and measure noise temperature (correcting for adaptor loss), remove 3 dB attenuator in path and ensure that change in DUT temperature <50 K.

Results for RF Linearity Test

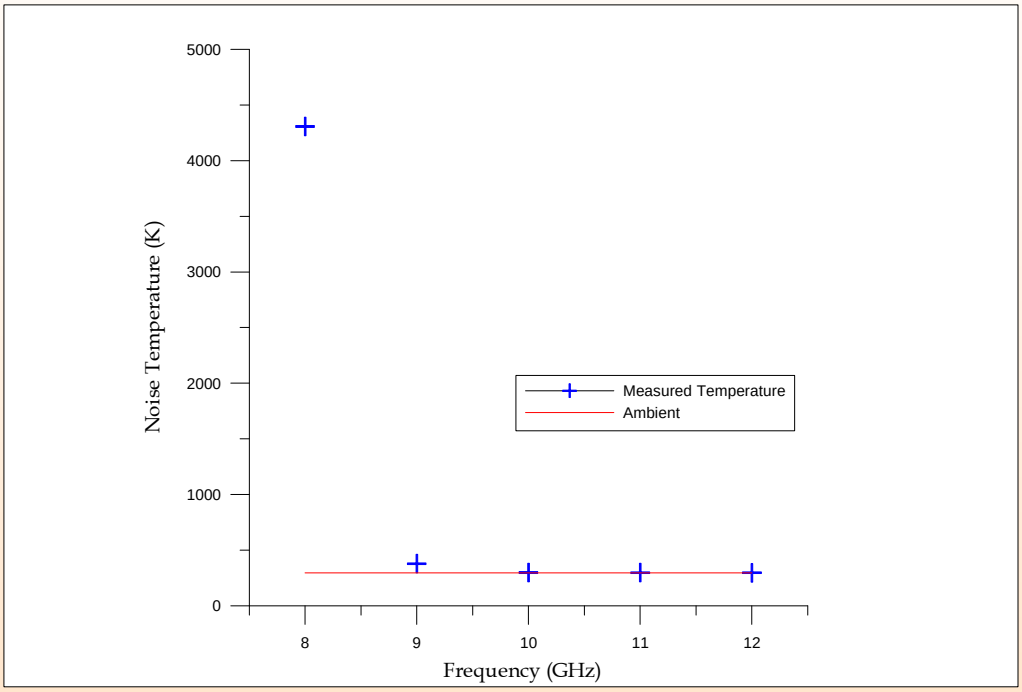


Spurious signals

- Use 8 GHz LPF to remove desired signal (*i.e.* noise from noise source); measured noise temperature should then be ambient temperature. Harmonics of lower frequencies will cause departure from ambient.

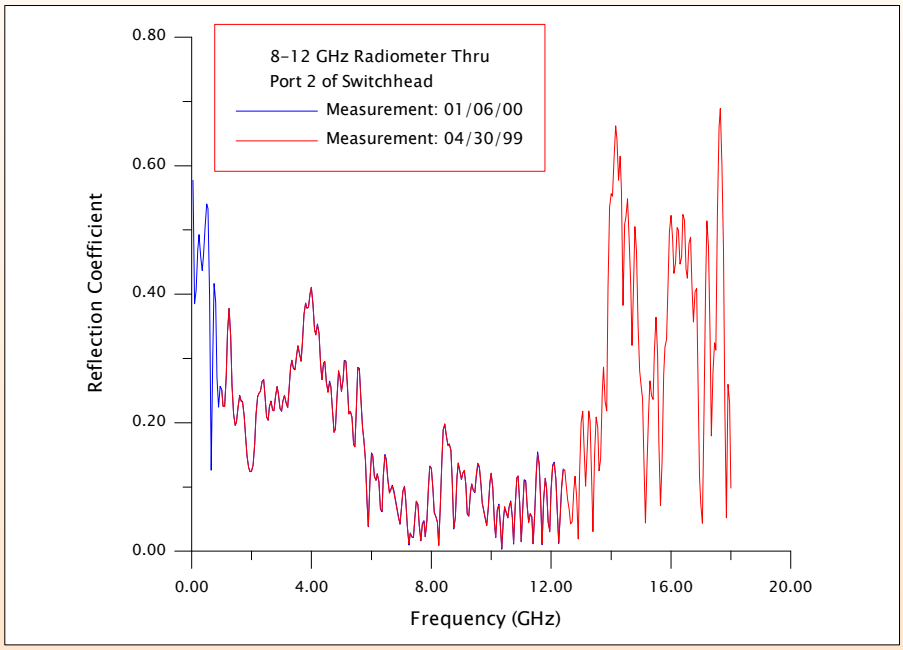


< Results of spurious signal test

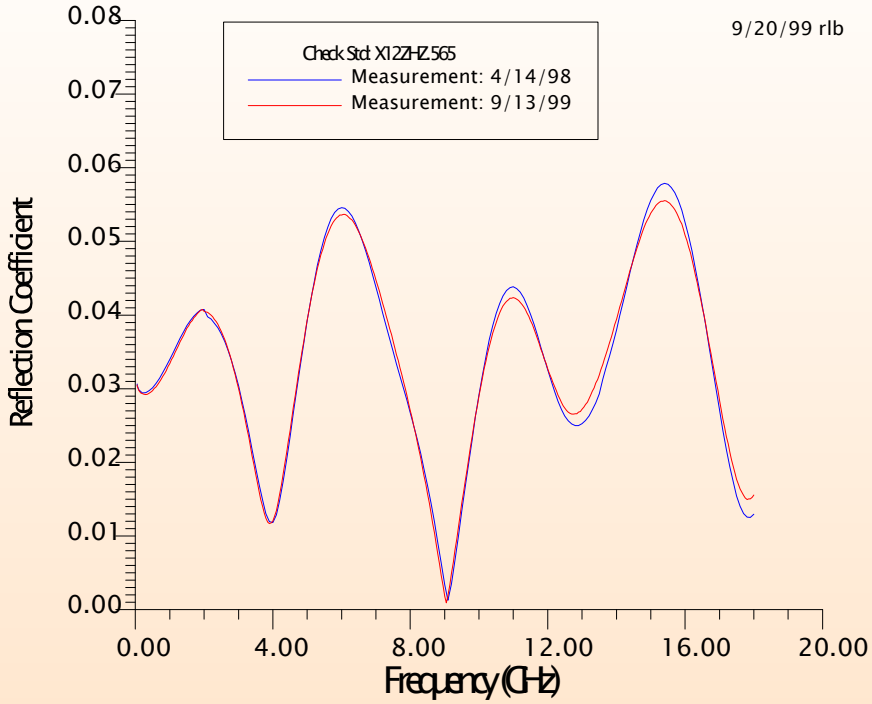


P Repeatability & time dependence

< "Typical" results

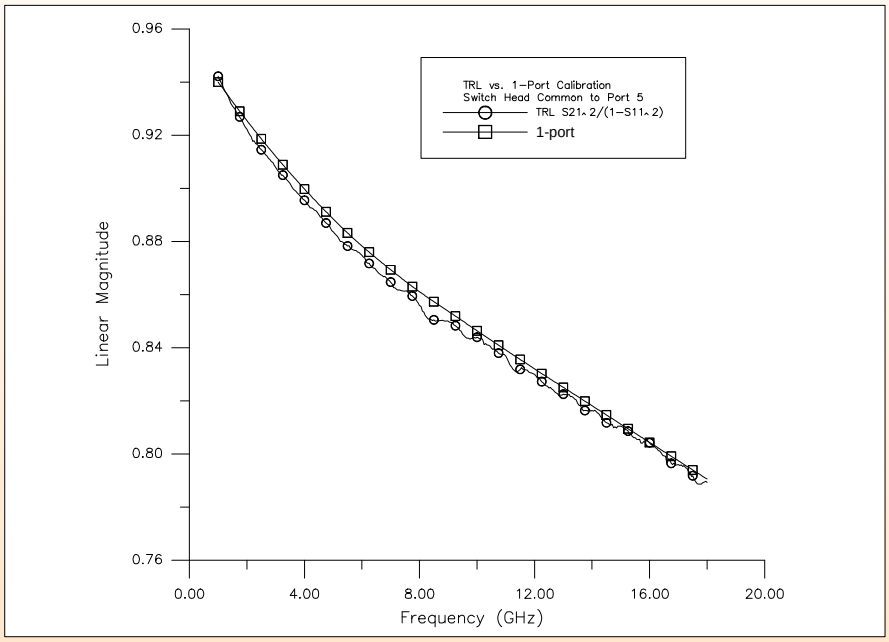


Repeatability of Reflection coefficients

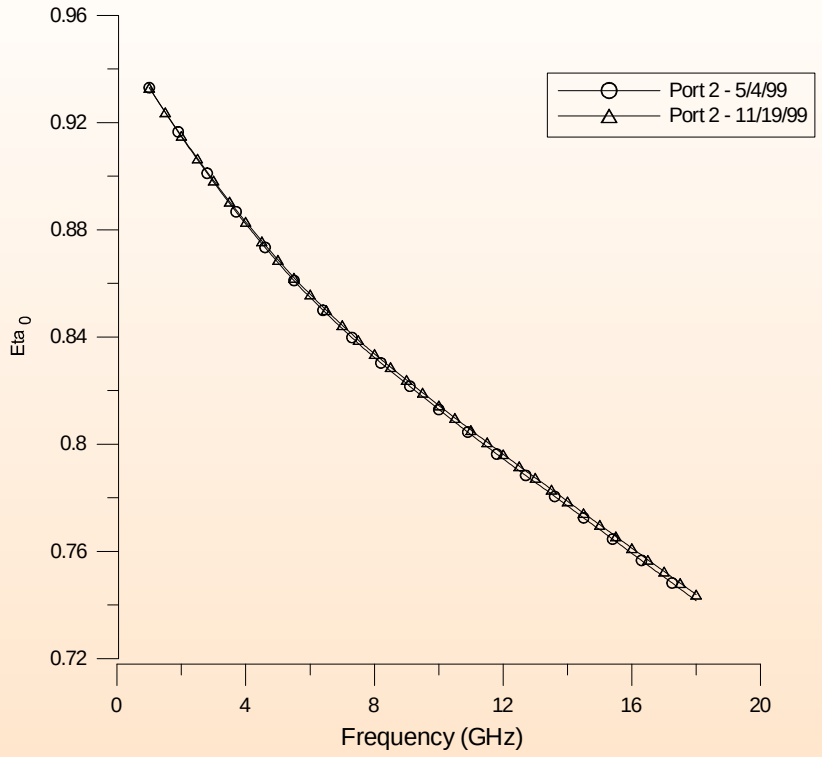


File: "noise/artifact/x1/X12ZHZ.565/graphs/ANA-MEAS.GRF"

< Comparison of efficiency measured with two different methods



Repeatabilility of efficiency of switch head



Uncertainties

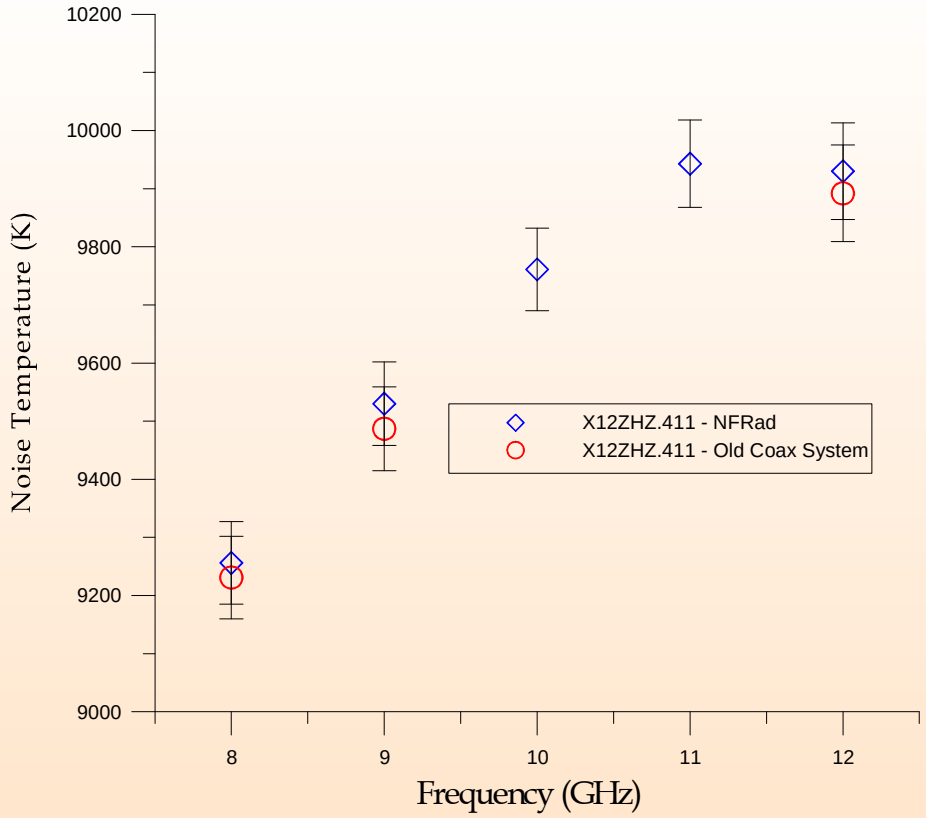
- Type A Uncertainties (Statistical)
  - Typically around 0.05 percent
- Type B Uncertainties (Systematic)

	8 GHz	10 GHz	12 GHz
Cryogenic Std	0.315	0.322	0.329
Ambient Std	0.047	0.047	0.047
Y-factor	0.000	0.000	0.000
Mismatch	0.120	0.073	0.194
Asymmetry	0.329	0.330	0.330
Isolation	0.015	0.010	0.021
Freq Offset	0.002	0.000	0.002
Nonlinearity	0.100	0.100	0.100
Total	0.484	0.480	0.517

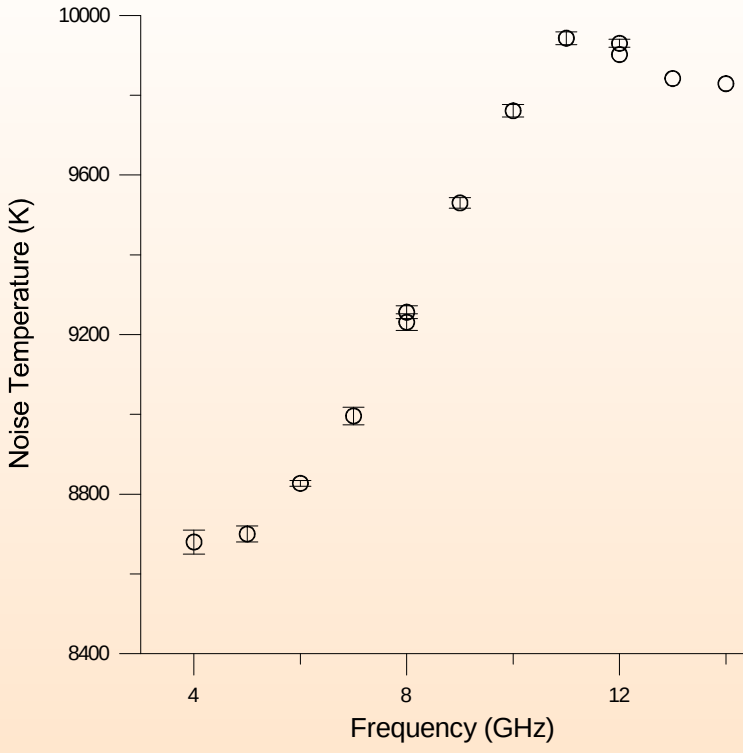
- Expanded combined (2F) uncertainties

$$U_{T_x} = 2\sqrt{u_A{}^2 + u_B{}^2} \approx 1\%$$

Comparison between the old coaxial system and NFRad



Results for NFRad4-8, NFRad8-12, and NFRad12-18



12/16/99